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Thermal alterations of the Ashua Formation at the contact with a porphyry intrusion (Huambo, south Peru): A reconnaissance study

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1. Introduction

In the Western Cordillera, in the Huambo district of the Arequipa region, a prominent porphyry stock intrudes an Upper Cretaceous unit (named Ashua Formation by Cruz, 2002), that consists of red beds of fluvial-evaporitic origin with intercalations of marine limestones, and the underlying unit consisting essentially of the shallow-marine limestones of the Arcurquina Formation. Both the petrography of the porphyry and hosting formations as well as the contact phenomena have not been described yet. They are the subject of the present article.

Most of the field observations and mesotectonic measurements come from a large quarry in a porphyry at the altitude of 3850-3950 m a.s.l., the nearby roadcut into the Ashua Formation, the northern slope above the entrance to the terminal tunnel of the Majes Project in Ashua, and the Quebrada Rodríguez, exposing both the intrusion and its sedimentary envelope. Laboratory investigations included traditional microscopy of thin sections in polarized light, the additional studies of fine-grained samples in scanning electron micropscope (SEM) as well as X-ray tests.

2. Arcurquina Formation

In the investigated area, only the upper sequence of the Arcurquina Formation is exposed, probably corresponding to the Cenomanian and Turonian. Bioclastic limestones and marly limestones reveal a significant amount of angular grains of quartz and alkali feldspars, as well as an admixture of biotite, chlorite and titanite. It suggests a short transport of acid pyroclastic material. Fractured dark limestones include gypsum veinlets while stripes of automorphic pyrite (or goethite pseudomorphs after pyrite) are present in the associated mudstones. In the upper section of the profile, zoogenic limestones (Fig. 1e) are intercalated with greenish clastics. These are quartz-calcite (coquina) sandstones and marls containing quartz, albite, glauconite, clinochlore, and illite. The Arcurquina Formation is unconformably covered by the succession of red mudstones, marly limestones and evaporites that is characteristic of the Ashua Formation. The unconformity was documented by mesotectonic measurements in both units.

In recent years, a new stratigraphic unit, the Ayabacas Formation, was introduced in the region, consisting of redeposited beds of the Arcurquina Formation (Callot et al., 2008). Its presence at the base of the Ashua Formation in the study area cannot be excluded.

3. Ashua Formation

The Ashua Formation appears to have only a local extent and to exhibit substantial lateral facies variations. It was described in detail in four profiles and redefined by M. Cruz (2002). The descriptions of the Ashua Fm known to us so far are based exclusively on megascopic observations and palaeontological examinations of marine fauna present in limestone intercalations. Fossils found there indicate the Coniacian–Early Santonian time interval (Jaillard et al., 1994). This was followed by a longer pause in sediment accumulation. The Ashua Fm is unconformably overlain by the continental Huanca Formation, which accumulated in the Eocene.

Alternating layers of red mudstones and sandstones prevail in the unit, which in the studied area is 300-350 m-thick. They are intercalated by lenticular conglomerates, limestones, marls, gypsum, and locally rock salt. Strata or laminae of fine-grained clastics are subordinate, and green, grey or yellow in colour. Sedimentological features indicate an overall upward gradual change from marine, and endoreic lacustrine environments into an alluvial one (Cruz, 2002).

Our studies have been conducted within a few hundred meters from the intrusion, with the aim of obtaining information about the original lithologies of the rocks that have been altered at the intrusive contact.

The detritic material of mudstones and sandstones consists mostly of subangular altered volcanic rocks, feldspars, and quartz, allowing to classify them as lithic wackes, litharenites and feldspathic litharenites. Cements contain calcite, gypsum, clay minerals (clinochlore, smectite, illite, mixed layer I/S and C/S), locally dolomite, vermiculite, barite, and/or celestite.

Limestones, apart from the dominant calcite, contain in some layers pyrite, dolomite, clay minerals, clasts of quartz and chalcedony, and authigenic albite. Gypsum beds may be monomineral or intergrown with dolomite, calcite, organic substance and minor palygorskite, and anhydrite. In the rock salt, lenticular microscopic plates of anhydrite are dispersed within the halite, and streaks and small jacks of red clay and black substance occur. The clayey fraction consists of quartz, calcite, illite, hematite, vermiculite and clinochlore. The rock salt is exploited in the artisanal Rodríguez salt mine.

Sedimentary environments indicated by M. Cruz (2002) have been confirmed, with the addition of sabkha and probably tidal flat environments.

4. Porphyry stock

The porphyry forms a marked intrusion that is 30 km-long and some 3 km-wide. It forms a local watershed ridge between the Quebrada Jaran depression and the Río Huambo passing into the source region of Río Seraj.

To the east, the intrusion hides below Pleistocene crystalloclastic tuffs of the Ampato volcano and is in contact with the Paleogene-age Huanca Formation (Palacios, 1991).

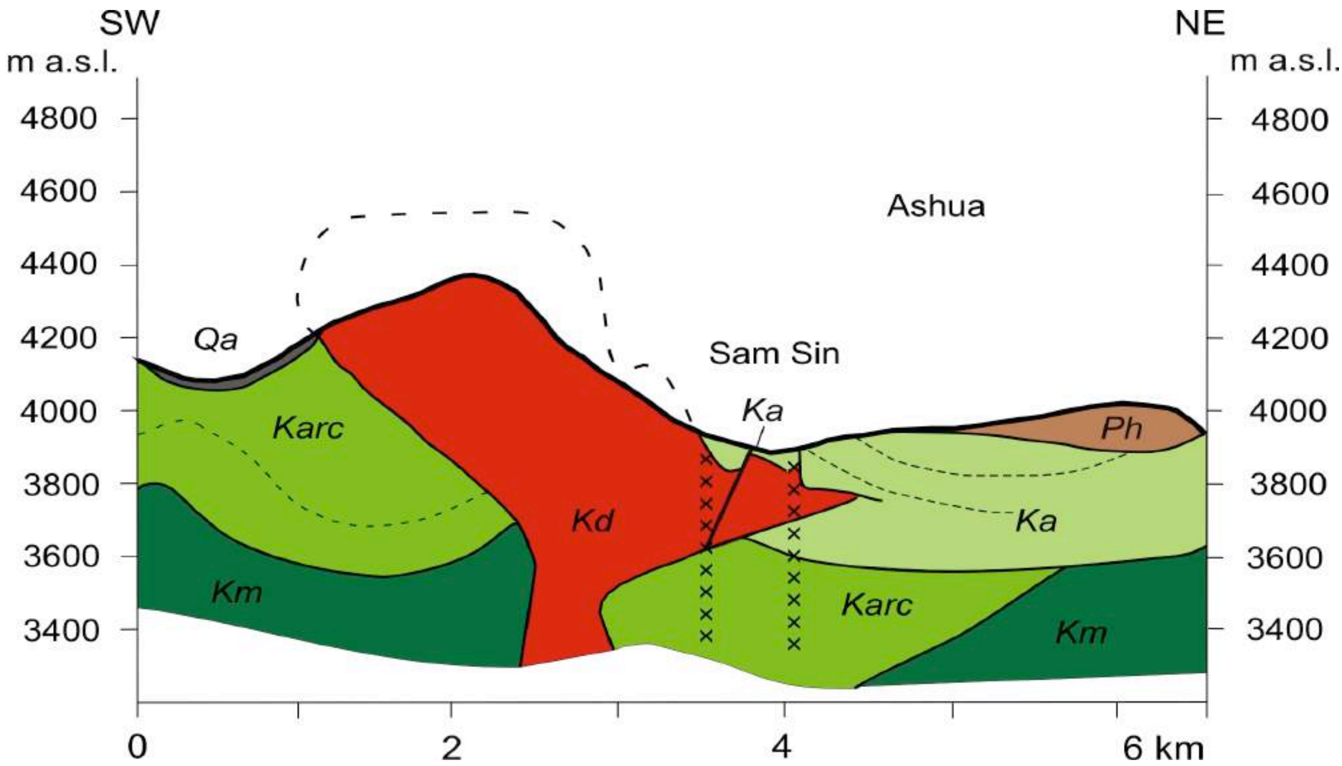

Figure 1. Cross-section of the porphyry stock at the studied quarry. Qa : Quaternary alluvia and deluvia. Ph : Huanca Formation (Paleogene). Kd : Late Cretaceous/Paleogene dacite porphyry. Ka : Ashua Fm (Late Creataceous). Karc : Arcurquina Formation (mid-Cretaceous). Km : Murco Fm (Early Cretaceous). xxx : mylonitized zones.

The porphyry intrudes the western flank of a syncline exposing the Ashua Fm and metamorphoses it along the contact. On the side of Jaran it is also in contact with the Arcurquina Fm. However, this contact is apparently mostly tectonic (post-intrusive). The relationship with the Huanca Fm is unclear due to an extensive alluvial cover, but seems to be partly tectonic, as figured in the cross-section in the Chivay geological map (Quispesivana & Navarro 2001).

We cannot confirm that the Chejol stock cross-cuts the Huanca Formation, which Huamán (1980) stated at Cerro Pallanca. This was an important argument in the interpretation of the intrusion age as Eocene or younger. On the other hand, Caldas (1993) stated that in Ashua, i.e.

close to Cerro Pallanca, the conglomerates of the Palaeogene Huanca Fm do not show any thermal alterations. On this basis he accepted that the stock in question was intruded during the Late Cretaceous or Early Palaeogene. Nevertheless, Quispesivana & Navarro (2001) described the rock as a tonalite, assigned it by analogy to the Yarabamba plutonic unit, which was thought to be related to the Incapuquio-Quellaveco fault zone and Toquepala volcanics (Zimmermann & Kihien, 1983; Alejandro et al. 2006), and thus attributed an Eocene age to the stock.

Near Ashua, at the edge of the Huambo depression, the porphyry apophysis drops out, being some 500 m-wide and 4 km-long. It goes to the upper part of Quebrada Rodríguez. In the vicinity of the intrusion, sandy beds of the upper part of the Ashua Fm are more compact, fractured and cut by veinlets of white and colourless zeolites. Zeolite veinlets, mostly greenish, cut the porphyry as well. The outer part of the intrusion is mylonitized and bleached along a narrow, 0.2-1 m-wide, zone along with surrounding rocks. The fresh rock can be classified as a porphyric phenodacite, with phenocrysts of white plagioclase, quartz, amphibole, and black mica.

A review of the bibliography reveals significant variations in the description of the rock. Caldas (1993), in his explanations to the Huambo geological map, describes it as a hypabyssal dacite porphyry, but in the legend of the map it is mentioned as a tonalite. Hosttas (1967), referring to a microscope analysis, uses the term porphyrite (quartz andesite). Huamán (1980) noticed compositional differences in distant outcrops of the intrusion classifying the rock as a porphyric microgranite (despite finding glass).

Under the microscope, the dacite in question shows 45-50 % phenocrysts, of which almost 40 % are leucocratic (intermediate plagioclase, alkali feldspar, and quartz) and 5-10 % mafic (pargasitic hornblende, phlogopite, sporadically acmite-augite). The matrix in the samples studied by us is fine-grained but holocrystalline. It contains the same minerals as phenocrysts as well as accessory magnetite, ilmenite, hematite, titanite, apatite, allanite, zircon. Iron and titanium oxides are associated with amphibole and mica and form numerous inclusions in them. Hematite tabular aggregates are frequently pseudomorphic after magnetite. The colour index is usually 15-20 %. Some plagioclase grains are zoned, and albitized at the phenocryst rims. Our XRD analysis identified disordered intermediate Na-Ca members as well as well-ordered albite. Some zones are party altered to sericite aggregate while others appear chloritized.

5. Altered rocks

In the quarry above Ashua the dacite apophysis is mylonitized and altered into bleached spotty rock. The mylonite abounds in zeolite veinlets in a zone that is 1-2 m-broad. The western mylonitic zone contains also fragments of roof pendants representing limestones and detritic rocks from the Ashua Formation. The eastern mylonitic zone, which is poorly exposed, seems to follow the foot of the apophysis close to the course of the Huambo-Pedregal road to the south of the quarry, and the Quebrada Sam Sin to the north of it. However, the northern part of the second zone near the road bridge exposes a steep contact of white mylonitized dacite and red Ashua mudstones, which are also tectonized and altered. The dacite in the centre of the quarry, i.e. in the central part of the apophysis, seems unaltered and reveals only weak albitization, K-feldspatization, and zeolitization of plagioclases. At megascopic inspection, some joints appear to be filled with semi-transparent or white radial zeolites (stellerite, stilbite), bluish-black Mg-riebeckite or red-brown K-richterite and green chlorite. Locally dark needles of tourmaline (dravite) are found.

Alteration of the mylonitized dacite is observed both in phenocrysts and matrix. The resulting rock is porous; larger voids are incrustated with zeolites, calcite and minor talc. Plagioclases are zeolitized, partly replaced by albite, anorthoclase, and/or microcline, and argillized (montmorillonite, illite). A broad set of eleven zeolite species was identified by the XRD method: scolecite, laumontite, leonhardtite, stellerite, stilbite (i.e., the Ca species) and mesolite, heulandite, Na-stilbite, clinoptilolite, Ca-clinoptilolite (the Na-Ca species), and Na-stellerite (the Na species). Some of them also carry potassium.

Hornblende phenocrysts turned initially into an alkali amphibole impoverished in iron and titanium, which were released in satellitic grains of magnetite (more seldom titanite or titanomagnetite) that form aureoles. Smaller amphibole grains in the matrix and more altered phenocrysts suffered alkali metasomatism. In their place Fe-clinochlore and a set of secondary amphiboles arose, i.e. tremolite, Na-tremolite, actinolite, edenite, pargasite, K-richterite, Mg-riebeckite, and arfvedsonite. They are intermingled with zeolites, locally calcite, hematite and other opaque minerals.

Pyroxene and mica are dispersed as minor constituents of the altered porphyry. Pyroxene was determined as acmite-augite, mica as phlogopite relics accompanied by vermiculite and mixed-layered chlorite/vermiculite, and chlorite/smectite.

Dense intergrowths and the heterogeneity of the mylonite material make petrographical studies difficult.

At the western contact of the mylonitized dacite, which includes roof pendants of Ashua limestones and grey sandstones, numerous veinlets of white and colourless transparent zeolites (stilbite, Na-stilbite, scolecite, clinoptilolite, mesolite, heulandite) with calcite and K-feldspars occur. They are irregular, some being 1 cm-thick. Other, generally thinner, veinlets contain calcite, Ca-Na zeolite, and green vitrous-acicular actinolite.

Limestones found as roof pendants are variable. Large fragments at some distance from the dacite are bioclastic, containing an abundant microfauna and detrital, angular to subrounded quartz grains ~0.1 mm in diameter. Other fragments, located in the mylonite zone, represent grey marble of granoblastic-porphyroblastic texture and stylolite-resembling streaks of reddish matter. The marble contains a mosaic of calcite and minor dolomite with 0.01-0.02 mm grains, nests and veinlets of crystalline calcite (0.3 mm), neosomal hypidiomorphic feldspars (0.2-0.5 mm) and plates, and radial sheaves of Ca-stilbite or Na-stilbite. The streaks abound in orthoclase and contain some hematite and opaline matter of cristobalite ordering. Brecciated marbles are cut by irregular clinoptilolite-clinochlore veinlets.

Mudstones and calcite-cemented sandstones prevail to the east of the dacite apophysis, i.e. in its floor. They are mostly red, with small white and green nests and streaks. They contain angular grains of quartz and feldspars cemented with clay minerals, locally carbonates or silica. Within ~1 m of the mylonitized contact with the dacite, neosomes of albite, orthoclase, hematite blasts are present in the red mudstones, while the accompanying white streaks are rich in talc. Tremolite, actinolite, and albite accompanied by diopside and epidote (pistacite) occur in greenish nests both in siliciclastic and marly rocks. The last assemblage, which is quartz-free, is characteristic of skarns. Otherwise, no amphibole knots typical of hornfels have been observed yet. Siliciclastic and marly rocks are cut by calcite, gypsum and zeolite veinlets.

In the outcrops described here, the contact aureole consists of skarns, calcitic marbles and chlorite-amphibole slates heavily overprinted by zeolite facies. The mineral assemblage indicates temperatures in the 300-500°C range in the case of diopside, epidote, amphiboles, and dravite, in the 200-300°C range in the case of chlorites, and in the 150-250°C range for relatively water-poor zeolites. Other zeolite species formed probably at still lower temperature intervals when pervasive metasomatosis gave way to the circulation and precipitation along fissures. The dacite itself suffered metasomatism leading to alkali amphiboles, chlorite, clay minerals and zeolites. In the Quebrada Rodríguez, some dacite pebbles derived from the contact zone contain monticellite veins, evidencing relatively high-temperature processes.

The described mineral assemblages are evidence of a dominantly alkaline metasomatism at pH 7–8 (compare with the diagram by Callegari & Pertsev, 2007).

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